Chapter 6: Conclusion

The goal of this thesis has been to gain a better understanding of the functional and neuropathological bases of syntactic comprehension deficits in PD. In this final chapter, I will summarize the approach that I have taken to achieve this goal and the conclusions that I have reached. I will also discuss a number of open questions that remain topics for future research.

In the first part of the thesis, which consists of Chapters 2 and 3, I presented the background information that is necessary for carrying out both theoretical and empirical research on the syntactic comprehension abilities of PD patients. Chapter 2 was devoted to reviewing the neuropathology and neuropsychology of PD. The main points that were made there are as follows. PD is a progressive neurodegenerative disorder that involves deterioration of the two dopaminergic projection systems in the basal ganglia. The nigro-striatal system is affected most strongly, causing severe dysfunction in the putamen in 100% of patients and less severe dysfunction in the caudate in roughly 50% of patients. The reduction of dopamine in these striatal nuclei prevents them from accurately recog-nizing behaviorally significant contexts in their massive input from the cortex and thalamus. As a result, the basal ganglia are no longer able to relay appropriate recommendations for thought or action to the frontal lobes via multiple specialized circuits. This lack of "biasing input" to certain regions of the frontal lobes leads to what DuBois et al. (1991) call "cortical demodulation." Since the putamen participates in a circuit with the motor cortices, all PD patients develop characteristic movement disorders; and since the caudate participates in circuits with the dorsolateral and orbital (and perhaps also ventrolateral) prefrontal cortices, about half of PD patients develop cognitive and emotional disorders as well. The mesocor-tical dopaminergic projection system is also affected in PD, albeit less severely than the nigrostriatal system. This leads to moderate dopamine depletion not only in the ventral striatum, which participates in a circuit with the anterior cingulate cortex, but also directly in the frontal lobes. Hence, the degeneration of the mesocortical system contributes to

the mental dysfunction of PD patients. Overall, without the influence of either the basal ganglia-thalamocortical circuitry or the direct mesocortical dopaminergic innervation, the prefrontal cortex is forced to "reason through" challenging cognitive problems that are normally handled much more quickly and easily. Indeed, a plethora of neuropsychological studies have shown that about half of PD patients exhibit cognitive deficits that are similar to those found in patients who have suffered lesions in the frontal lobes. These patients generally perform well on visuospatial, memory, and attentional tasks that provide clear environmental guidelines for response formation or selection, but perform poorly on tasks that require them to rely entirely on internal cognitive resources. In particular, they have difficulty regulating mental "sets" by either shifting from one to another or by maintaining one despite interference from others.

The focus of Chapter 3 was on constructing a model of the normal syntactic comprehension system that could be used as a frame of reference for specifying and testing predictions about the nature of syntactic comprehension deficits in PD. Following current methodological practice in cognitive neuroscience, the model that I offered contains three different levels of analysisùstructure, processing, and neurobiology. The first level characterizes, from the point of view of RRG, the kind of syntactic and semantic structures that occur in various linguistic constructions, as well as the way in which the syntactic structure is mapped onto the semantic structure. The second level addresses the processing operations and resources that are dedicated to assembling syntactic and semantic structures and linking the former to the latter during the course of on-line sentence processing. More precisely, on the basis of both computational analyses and empirical psycholinguistic studies, I postulated a set of fairly specific parsing and linking operations as well as two processing resourcesùnamely, syntactic STM and attentional control. Finally, the third level is concerned with the brain areas that physically implement the major components of the syntactic comprehension system. I argued that the left perisylvian cortex is dominant for syntactic comprehension in the vast majority of the population (over 90%), but that it is difficult to find more narrowly defined cortical areas that are reliably associated with specific aspects of syntactic comprehension. Nonetheless, I suggested the following localization trends: parsing is typically implemented in the anterior perisylvian cortex, perhaps in the anterior third of the superior temporal cortex; interpretation is typically implemented in the posterior perisylvian cortex; syntactic STM is typically implemented in the pars opercularis of Broca's area; and attentional control is typically implemented in the anterior cingulate cortex, ventrolateral prefrontal cortex, and basal ganglia.

By combining this multilevel model of the normal syntactic comprehension system with the review of the neuropathology and neuropsychology of PD in the previous chapter, I was able to formulate a general hypothesis about the syntactic comprehension abilities of PD patients. I proposed that roughly 50% of PD patients should have difficulty under-standing constructions that depend on attentional control for regulating template selection and linking in a top-down manner. Such constructions often have complex constituent structure together with noncanonical linking which is signaled by few or no explicit mor-phosyntactic cues; hence, they require shifting from a routine processing strategy to a non-routine processing strategy and maintaining the latter in the face of interference from the former. The prediction that PD patients should have trouble with constructions of this type is motivated by two main considerations: first, attentional control for syntactic comprehen-sion is implemented in brain areas that are known to be affected in PD; and second, neuro-psychological studies of PD patients have shown that one of their major cognitive deficits involves an inability to regulate various kinds of mental "sets" in a top-down manner, espe-cially when there is little or no guidance from the environment. In addition to proposing that PD patients should have trouble with constructions that require attentional control, I also suggested that they should *not* have trouble with constructions in which the only com-plex processing factor is parsing, or with constructions that require noncanonical linking but provide multiple explicit cues for this. With regard to the processing resource of syn-tactic STM, I pointed out that a firm prediction as to whether it is impaired in PD patients cannot be made, because it is not known whether a circuit exists that relates the basal ganglia to the ventrolateral prefrontal cortex (where Broca's area resides), or whether this cortical region receives a heavy dopamineric innervation via the mesocortical projection system.

The second part of the thesis, which consists of Chapters 4 and 5, was devoted to testing the predictions set forth at the end of Chapter 3. In Chapter 4, I summarized and critically evaluated ten previous studies that have focused on syntactic comprehension deficits in PD. I argued that many of these studies suffer from problems involving experi-mental design, data analysis, and/or the explanation of performance profiles. However, I also showed that of the seven studies that are directly relevant to my predictions, all of them provide results that largely support the predictions. Not only do these studies demon-strate that roughly half of PD patients exhibit syntactic comprehension deficits, but they also indicate that the kinds of constructions that cause trouble for PD patients are precisely the ones that should do so, according to the hypothesis that the patients have an impairment of attentional control. For instance, Grossman et al. (1992b) found that PD patients per-formed significantly worse on center-embedded object-relatives than on center-embedded subject-relatives. In itself, this result is consistent with several hypotheses about the nature of the underlying deficitùit could involve complex parsing, noncanonical linking, syntactic STM, or attentional control. Other findings, however, appear to rule out all but the last possibility. Thus, the patients displayed variable performance when tested on the same materials in different sessions, which is hard to reconcile with the view that they have a parsing impairment. They also performed well on passive sentences, which is incom-patible with the view that they have an impairment of noncanonical linking. Furthermore, they performed well on an independent test of syntactic STM, which raises doubt about the possibility that they have an impairment of this processing resource. The most coherent explanation of the overall pattern of data, then, is that PD patients have an impairment of attentional control. With respect to neurobiological issues, the finding that syntactic STM appears to be intact suggests the absence of either a circuit relating the basal ganglia to the ventrolateral prefrontal cortex or a heavy dopaminergic innervation of the ventrolateral prefrontal cortex. However, this is by no means definitive, since it could be that Grossman et al.'s test of syntactic STM was not demanding enough to reveal a disturbance.

In Chapter 5, I presented four new studies that were designed to test PD patients on a variety of constructions which they have not been tested on before, and also to further explore the predictions of the hypothesis that such patients have an impairment of attentional control. These studies show that around half of PD patients exhibit the following dissociations: canonical subject-to-subject raising sentences (good) vs. noncanonical subject-to-subject raising sentences (bad); canonical object-to-subject raising sentences (good) vs. noncanonical object-to-subject raising sentences (bad); center-embedded subject-relatives (good) vs. center-embedded object-relatives (bad); terminal subject-relatives (good) vs. terminal object-relatives (bad); and subject-clefts (good) vs. object-clefts (bad). In addition, the studies show that PD patients typically do *not* exhibit dissociations between the following other constructions: transitive active sentences vs. passive sentences (foregrounding and backgrounding); active undergoer-control sentences vs. passive undergoer-control sentences; and actor-intransitive sentences vs. undergoer-intransitive sentences. Finally, the studies indicate that very few PD patients manifest problems on pairs of constructions that differ only with respect to whether they require syntactic STM. As I argued in Chapter 5, this entire set of results is consistent with the hypothesis that PD patients have an impairment of attentional control. By contrast, certain aspects of the results are inconsistent with three alternative hypotheses. First, the

finding that PD patients generally do not perform significantly worse on passive undergoer-control sentences than on active undergoer-control sentences disconfirms the hypothesis that they have an impairment of complex parsing. Second, the finding that PD patients have good comprehension of foregrounding and backgrounding passive sentences, undergoer-intran-sitive sentences, and passive undergoer-control sentences disconfirms the hypothesis that they have an impairment of noncanonical linking. And third, the finding that PD patients tend to perform well on independent tests of syntactic STM disconfirms the hypothesis that they have an impairment of this processing resource (although, as noted earlier, it should be kept in mind that such patients might exhibit a decrement in performance if tested with
more demanding measures of syntactic STM).

As this terse summary of the thesis has revealed, there is a substantial amount of support for the notion that the underlying cause of syntactic comprehension deficits in PD is an impairment of attentional control. Nonetheless, there are still a number of issues that I have not fully addressed or have not dealt with at all. I will conclude by mentioning several of them.

In developing a model of the normal syntactic comprehension system in Chapter 3, I did not elaborate the processing resource of attentional control in very much detail, even though in the second part of the thesis I used this component of the system as the foundation for characterizing the nature of the disorder in PD. As I pointed out in Chapter 3, very little research has been done on the role that attention plays in on-line sentence proces-sing. Carpenter and her colleagues have conducted a few interesting studies, but these studies are of limited value for two main reasons. First, although Just and Carpenter (1992) designed a computer model that simulates many effects of attentional demands on sentence processing, this model treats attentional control and short-term memory as a single computational resource with a common pool of activational capacity. Other researchers have also neglected to distinguish between the different processing tasks of these two resourcesùe.g, Caplan and Hildebrandt (1988) posit a highly general resource called the "syntactic comprehension workspace," and Frazier and Friederici (1991) posit a similarly general resource called "computational capacity." I have tried to go beyond this level of analysis by arguing on both engineering and neurobiological grounds that attentional control and syntactic short-term memory are functionally distinct processing resources which are implemented in distinct brain areas. The second limitation of the studies that Carpenter and her colleagues have done is that they have focused primarily on only one pair of constructionsùcenter-embedded subject-relatives and object-relatives. Extrapolating from these studies, I offered some suggestions about which other constructions do and do not require attentional control. These suggestions, however, need to be tested through psycholinguistic and neurolinguistic experimentation. Psycholinguistic paradigms that could be used include the following: measurement of reaction times, pupil dilation, or backward saccades during reading, and measurement of reaction times in dual-task situations. Several powerful neurolinguistic methodologies are also available: event-related potentials, functional MRI, MEG (i.e., magnetoencephalography), and PET.

Continuing with the topic of attentional control for syntactic comprehension, an interesting question which I did not discuss is whether this processing resource is specialized for the domain of language or applicable to other domains as well. Support for the view that attentional control is a general-purpose resource comes from Seidl et al.'s (1995) dual-task study in which sentence processing was the primary task and verbal or visuospatial processing was the secondary task (see º 4.3.4, pp. 210-13). The results showed that performance decreased for both PD patients and control subjects as both kinds of task became increasingly more challenging. This suggests the existence of a single executive attentional resource which has limited capacity and can be allocated to multiple domains simultaneously (see also Posner et al. 1987). Additional support for the general-purpose view of attentional control comes from the fact that the anterior cingulate

gyrus, which is a well-established anatomical substrate for this processing resource, is activated in attention-demanding tasks regardless of the content domain (Devinsky et al. 1995; Frith & Grasby 1995). On the other hand, there is also evidence for the view that attentional control is not a completely general-purpose processing resource but is instead fractionated into a number of domain-specific components. Grossman et al. (1992b) provided some behavioral support for domain-specificity, since they found that some PD patients exhibited dissocia-tions between syntactic comprehension tests and neuropsychological tests of executive functioning. This finding must be interpreted cautiously, however, because as I argued in my evaluation of this study, none of the neuropsychological tests that Grossman et al. used focused on set-regulation, which is the aspect of attentional control that I suggested is most important for syntactic comprehension. Neurobiological support for multiple domain-specific attentional systems comes from the finding that even though the anterior cingulate gyrus is reliably activated in different kinds of attention-demanding tasks, distinct subareas of this brain region tend to be activated for visuospatial and linguistic tasks (Frith & Grasby 1995). Moreover, at a finer anatomical level of analysis, researchers have found distinct sets of cortical columns in the anterior cingulate gyrus of monkeys such that some columns are connected with the parietal lobeùa region that is involved in visuospatial processingù while other columns are connected with the ventrolateral prefrontal cortexùa region that
is involved in linguistic processing (Vogt et al. 1992; Posner & Raichle 1994). Further support for the view that attentional control is domain-specific comes from computational considerations. If it is the case that the function of attentional control for syntactic com-prehension is to influence the selection of templates and associated linking strategies in a top-down manner, the attentional component must contain a considerable amount of know-ledge about the grammar of the language. For example, it must know that for subject-object relative clauses like *The boy that the girl chased knows me*, the correct template and linking strategy is the one that maps the head NP onto the undergoer

macrorole and the preverbal NP onto the actor macrorole. This kind of knowledge is necessarily domain-specific, and there does not appear to be any way in which attentional control could accom-plish its task without such knowledge. I conclude, therefore, that although attentional control for syntactic comprehension is in many respects functionally and neurobiologically similar to attentional control for other domains, it is nonetheless specialized for dealing with the domain of sentence processing.

This view leads directly to a series of very difficult questions about the nature of this processing resource: Exactly what sort of knowledge does it contain? How is this know-ledge organized and applied? How does it develop during the course of language acqui-sition? I will not attempt to answer any of these questions in detail now, but I will suggest some directions that future research could take. Grafman (1995) has developed a represen-tational theory of the prefrontal cortex which states that this enormous part of the brain stores high-level representations called "managerial knowledge units" (MKUs) and "struc-tured event complexes" (SECs), analogous to the frames, schemas, scripts, story gram-mars, etc. that have been discussed in the cognitive science and artificial intelligence litera-ture. MKUs and SECs are organized in a hierarchical, domain-specific fashion. For instance, there are domains for social behavior, appetitive behavior, linguistic behavior, mechanical behavior, and so on. Each of these domains is further subdivided, so that, for instance, the social domain consists of subdomains for mating, status-striving and reputa-tion maintenance, reciprocal exchange of favors, etc. The subdomain of mating itself consists into collections of MKUs and SECs for dating behavior, marriage behavior, seduction behavior, sexual behavior, etc. Grafman describes how MKUs and SECs are structured, how they are processed, how they interact with one another, how they develop, and how they are impaired following brain damage. This general theory of prefrontal cortical function leads to the possibility that the knowledge contained in the attentional component of the syntactic comprehension system is organized in terms of "packets" of information about the structural and processing requirements of not only hierarchically arranged categories of grammatical constructions (e.g., relative clauses, raising construc-tions), but also very specific constructions (e.g., subject-object relatives). These packets of information may develop during language acquisition through a process of "redescrip-tion" and "explicitation" of regularities that are identified in the grammar of the language (Karmiloff-Smith 1992).

Shifting to other topics, another issue that warrants further investigation is the status of syntactic STM in PD patients who exhibit syntactic comprehension deficits. Two different tests of this processing resource have been used. First, both Grossman et al. (1992b) and I (in Study 3) evaluated the ability of PD patients to answer probe questions that focus on either adjacent or nonadjacent portions of target sentencesùe.g., adjacent (syntactic STM not required): *The girl pushed the boy that is tall. Who is tall?;* nonadjacent (syntactic STM required): *The girl that pushed the boy is tall. Who is tall?* Only three of the 20 patients in Grossman et al.'s study performed significantly worse on the latter construction than on the former, and none of the 15 patients in my study did so. Second, in Study 2 I evaluated the ability of PD patients to answer probe questions for overt pronoun and zero anaphora sentencesùe.g., overt pronoun (syntactic STM not required): *The boy helped the girl and then he watched TV. Who watched TV?;* zero anaphora (syntactic STM required): *The boy helped the girl and then watched TV. Who watched TV?* Only two of the nine patients performed significantly worse on the latter construction than on the for-mer. These results suggest that syntactic STM is not affected in the vast majority of PD patients. However, as I have pointed out several times, neither of these tests places heavy demands on syntactic STM. Thus, it could be that further experimental work using more challenging materials will uncover at least a mild deficit. The normal syntactic comprehen-sion system is designed to handle even very long-distance dependencies in sentences, as illustrated in the following examples where the underlined stretch of words represents the portion of the sentence over which syntactic STM is required: *The girl wondered who John believed that Mary claimed that the baby* *saw; Reverse the clamp that the stainless steel hex-head bolt extending upward from the seatpost yoke holds in place* (from Pinker 1994: 220-1). It would certainly be interesting to find out whether PD patient have the syntactic STM capacity necessary to process sentences like these.

Yet another issue that constitutes a topic for future research involves the relation between cognitive deficits and syntactic comprehension deficits in PD. Lieberman et al. (1992), Grossman et al. (1992b), and McNamara et al. (in press) included in their studies linguistic tests as well as standardized neuropsychological tests. Lieberman et al. found significant correlations between, on the one hand, deficits in speech production and syntactic comprehension and, on the other hand, deficits on tests of set maintenance (the Odd Man Out Test) and concentration (the backward part of the Digit Span Test) on the other hand. Such a correlation is exactly what one would expect, given the neuropathology and neuropsychology of PD; however, as I pointed out in my evaluation of Lieberman et al.'s study, the results are of limited value because the test of syntactic comprehension was not designed to isolate any specific processing factors, such as complex parsing, noncanonical linking, syntactic STM, or attentional control. Grossman et al. (1992b) administered a large battery of neuropsychological tests to their patients, but found very few correlations between the patients' performance on these tests and their performance on the tests of syntactic comprehension. The problem with this study is the opposite of the problem with Lieberman et al.'s: the test of syntactic comprehension was, for the most part, well designed, but none of the neuropsychological tests were designed specifically to measure the ability to use internal attention control for set regulation. If such tests had been used, significant correlations might have appeared. Finally, McNamara et al. (in press) compared the performance of PD patients on both sentence processing tests and the Wisconsin Card Sort Test, which is an excellent measure of working memory and attentional control. However, the researchers found only marginal correlations, most likely because, as I argued in Chapter 4, their tests of sentence processing did not really

tap the processing resources of memory and attention. In planning my own Study 3, I originally intended to include a version of the Stroop test similar to the version that Brown and Marsden (1988b) used (see º2.2.3, pp. 37-8), the reason being that this test places a heavy load on internal attentional control for inhibiting a routine processing strategy and promoting a nonroutine processing strategyùthe same kind of attentional control that I suggested is required for understanding certain kinds of grammatical constructions. Ultimately, however, I was
not able to administer this test to the PD patients who participated in the study. Thus, it remains for future research to determine the extent to which the performance of PD patients on syntactic comprehension tests correlates with their performance on tests of prefrontal function, especially attentional control.

Another issue has to do with the kinds of methodologies that have been used to evaluate the syntactic comprehension abilties of PD patients. All of the studies that have been done so far, with the possible exception of Seidl et al. (1995), have employed off-line paradigms such as requiring patients to respond to probes or match sentences with pictures. These studies have revealed deficits that can be accounted for best in terms of an impairment of attentional control. However, it is conceivable that the deficits do not exist at the level of on-line sentence processing, but rather at the level of so-called "post-interpretive proces-sing," that is, the level at which attentional resources must be allocated over the final repre-sentation of a sentence in order to carry out the task of responding to a probe or matching the sentence with the appropriate picture. In a series of detailed case studies of aphasic patients, Tyler (1992) found dissociations of precisely this sortùnamely, intact on-line processing but impaired off-line processing. She did not provide any lesion data about her patients, however, which makes it impossible to know whether the brain areas that are affected in these patients are similar to those that are affected in PD patients. Nonetheless, the fact that some brain-damaged patients exhibit such dissociations indicates that it is very important for future investigations of the sentence processing abilities of PD patients to use on-line paradigms. Several paradigms of this kind are available. Most of them involve reaction times for button-presses, however, and this might present a problem for PD patients, since they have movement disorders that include slowness of execution. The ideal on-line paradigm for investigating PD patients is probably event-related potentials, since this approach does not require any motor response whatsoever. In fact, it would be very interesting to measure ERPs in PD patients as they process center-embedded subject-relatives and object-relatives, and then compare the results with the study of these same constructions that King and Kutas (1995) conducted. The prediction is that if PD patients have an impairment of the on-line application of attentional control, they should exhibit ERP profiles similar to, but more exaggerated than, the profiles exhibited by the "low capacity" subjects in King and Kutas's study (see º3.2.2.2, p. 102, and º3.3.2.5, pp. 138-9). On-line techniques such as ERPs could also be used to explore another possible cause of syntactic comprehension deficits in PDùnamely, slowed information processing. The final issue that I will discuss is about how PD patients who speak other languages might perform on syntactic comprehension tests. In particular, it is important to note that

in many other languages, raising constructions and relative clause constructions often provide explicit cues that signal the appropriate linking pattern. Consider, for example, the following two raising sentences from Icelandic (Van Valin & LaPolla, in press):

a. Harald-ur virthist haf-a far-ith heim.
Harold-MsgNOM seem.3sgPRES have-INF go-PSTP home
'Harold seems to have gone home.'

b. Peim virthist hafa pott Olaf-ur leithinleg-ur.
3plDAT seem.3sgPRES have.INF think.PSTP Olaf-MsgNOM boring-MsgNOM
'They seem to have found Olaf boring.'

In (a) the pivot NP receives nominative case, which is the default. As a result, it is not immediately clear what semantic role this NP will have in the dependent core. The proper interpretation can only be determined when the relevant material in the dependent core is encountered. Thus, in order to process Icelandic raising sentences that have normal case-marking in the matrix core and noncanonical linking in the dependent core, attentional control might be needed to regulate the selection of the appropriate template and linking strategy. One would therefore expect PD patients to have difficulty understanding such sentences. By contrast, in (b) the pivot NP is "quirky" case-marked as dative, since the verb *pott* requires this. As a result, it is clear from the outset what semantic role the NP will play in the dependent core, and hence attentional control is not needed, even when the linking pattern in the dependent core is noncanonical. PD patients should therefore not have trouble comprehending such sentences. Other languages, especially those that have rich inflectional systems, provide explicit morphological cues for parsing and interpretation. For instance, in German all relative clauses begin with a pronoun which codes for the role that the head NP plays in the relative clauseùnominative, accusative, dative, or gen-itive. Such cues make on-line processing easier for the listener and hence diminish the need for top-down attentional intervention. An important direction for future research is to investigate whether PD patients are able to understand such constructions despite having an attentional impairment.